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SEWAGE TREATMENT PLANT AT THE GRAND CANYON NATIONAL PARK

BY

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SEWAGE TREATMENT PLANT AT THE GRAND CANYON NATIONAL PARK [1]

By H. B. Hommon,[2] *Sanitary Engineer, United States Public Health Service*

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The Grand Canyon National Park, created by act of Congress, February 26, 1919, is one of the 19 national parks administered by the National Park Service, under the Department of the Interior. It lies in the northern part of Arizona and has an area of 958 square miles. Within this area the Colorado River flows through 56 miles of gorge or canyon which is over a mile deep and 20 miles wide at the top in places. The park derived its name from this canyon. Most of the visitors to the park have, in the past, gone to the south rim, where there are hotels, stores, and an automobile camp. The data given in this paper refer to sewage disposal at the south rim. An extensive building and development program is now under way on the north rim, but up to the present time only a comparatively few people have ever visited the territory in the park to the north of the Colorado River.

WATER SUPPLY

The water supply for the south rim, furnished by the Santa Fe Railroad Co., is ordinarily hauled in tank cars from Flagstaff, Ariz., a distance of about 100 miles. When this supply becomes low, water is obtained from Puro, Ariz., which is about 120 miles from the canyon. The cost of bringing in water from Flagstaff is $3.09 per 1,000 gallons, and the amount delivered during the peak of the tourist season, when there are approximately 2,400 people in the park, averages about 100,000 gallons daily.

The only sources of water supplies in the territory around the south rim are (1) the San Francisco Mountains, about 52 miles away; (2) Bright Angel Creek, about 6 miles away and at about 5,000 feet lower elevation; (3) some springs approximately 2 miles distant and about 3,500 feet below the rim of the canyon; and (4) the Colorado River. No attempt has ever been made to develop either of the first two sources, on account of the cost, and the spring supply has been in litigation until recently. The Colorado River has not been considered as a source of supply on account of the high turbidity of the water throughout the year at the place where a pumping plant could

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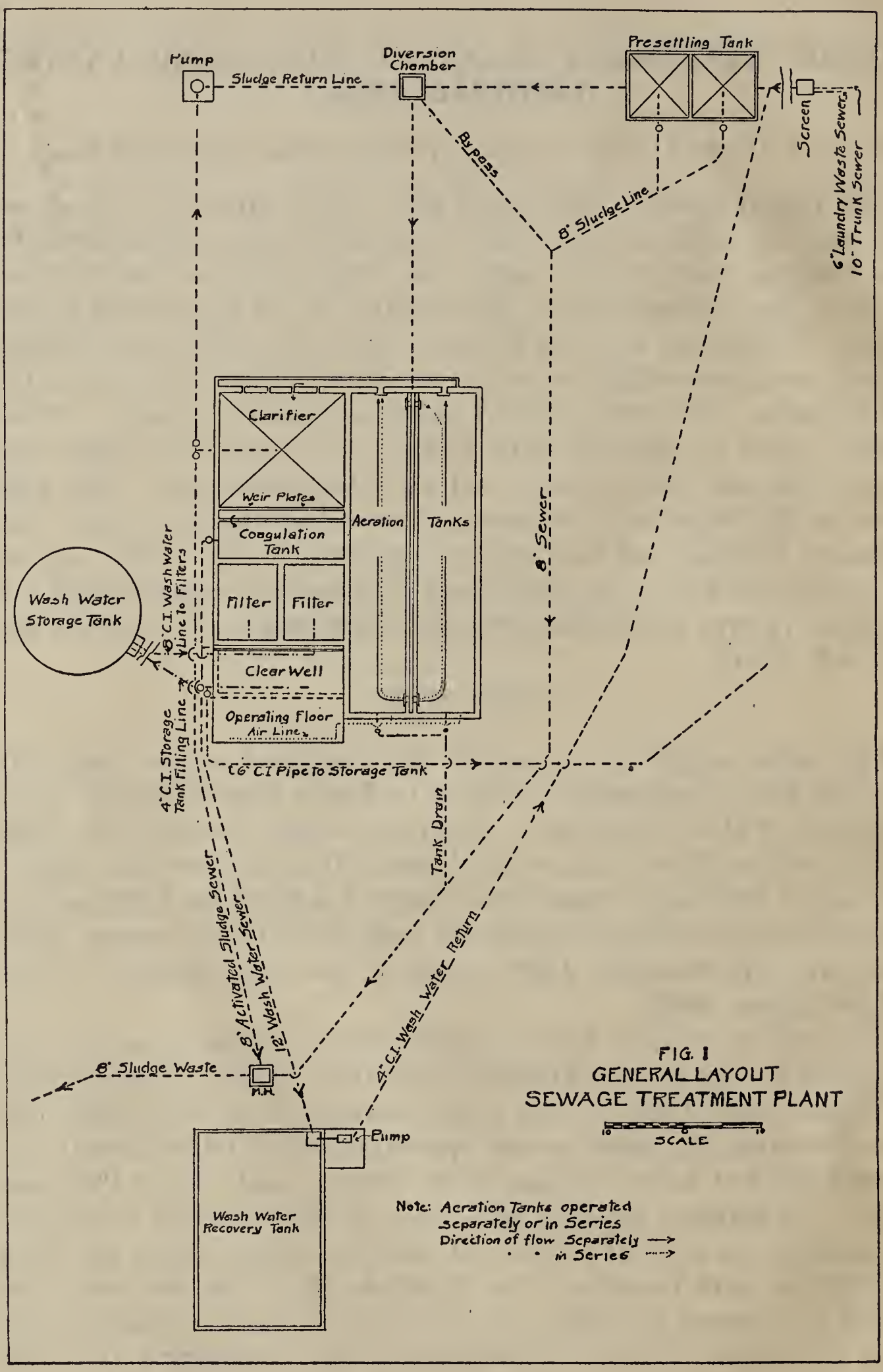
be installed, and because of the expense of a 6-mile pipe line and the cost of raising the water approximately 5,000 feet.



SEWAGE DISPOSAL

When the Santa Fe Railroad Co. began extensive developments at the south rim, before the Grand Canyon National Park was created,

Fig. 2.—General view of sewage treatment plant. (1) Wash water return line; (2) presettling tank; (3) diversion chamber; (4) valve on line from air channel; (5) aeration tanks; (6) clarifier; (7) house over sand filters, clear well, pumps, and motors

Fig. 3.—Air supply pipes to channels under filtros plates

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a sewage treatment plant, consisting of septic tanks, contact filters, and pressure sand filter, was constructed to treat the sewage so that the effluent could be used for irrigating lawns and for boiler purposes. The effluent, however, was always putrescible, contained hydrogen sulphide and could not be used for irrigating lawns near the hotel, and it was not satisfactory for boiler purposes. There was also a decided odor in the vicinity of the plant. The laundry waste caused foaming in the boilers, and was by-passed around the treatment plant.

In 1924 the number of visitors to the park had increased to such an extent that it was necessary to make extensive improvements to the railroad terminal facilities, improve the roads, and adopt a comprehensive development plan for hotels, residences, stores, garages, etc., to take care of the visitors and employees. The problem of supplying water for the increased population was acute, and in the general plan worked out for major improvements there was included a new sewerage system and a sewage treatment plant that would purify the sewage so that it could be used for as many purposes as possible in place of fresh water.

On account of the troubles experienced in using the effluent from the old treatment plant in boilers, when the laundry waste was treated along with the domestic sewage, a separate sewer line was included in the design of the sewerage system to carry the laundry waste to the by-pass around the treatment plant.

TREATMENT PLANT

Since it was desired to purify the sewage so it could be used in place of fresh water, for certain purposes, methods of treatment were considered which would produce, consistently, the highest quality of effluent under the climatic and other conditions at the canyon. Settling tanks, slow sand filters, and sterilization would produce a satisfactory effluent, but the high cost of sand (approximately $7 per yard) and the difficulties of operation during the winter at an elevation of 6,800 feet, made this method impractical. Settling tanks, sprinkling filters, slow sand filters, and sterilization would also produce an effluent of the highest quality, but the high cost of materials and the severe winters precluded the adoption of this method. There remained, therefore, the activated sludge process, rapid sand filters, and sterilization as the method which could be operated with the least difficulties in the winter, which would produce throughout the year an effluent of the quality desired, and would require the smallest amount of material to be shipped to the canyon. In the following paragraphs there is given a description of the treatment devices installed. The layout of the plant is shown in Figure 1, and a general view in Figure 2.

Screen.—A coarse bar screen is located in a screen chamber on the trunk sewer line near the inlet to the presettling tank. It is 3 feet wide by 3 feet deep and has ⅜-inch by 2-inch rectangular iron bars spaced 2⅜-inch on centers. The bars are embedded in concrete at the top and bottom, and slope in the direction of flow of the sewage at an angle of 30°.

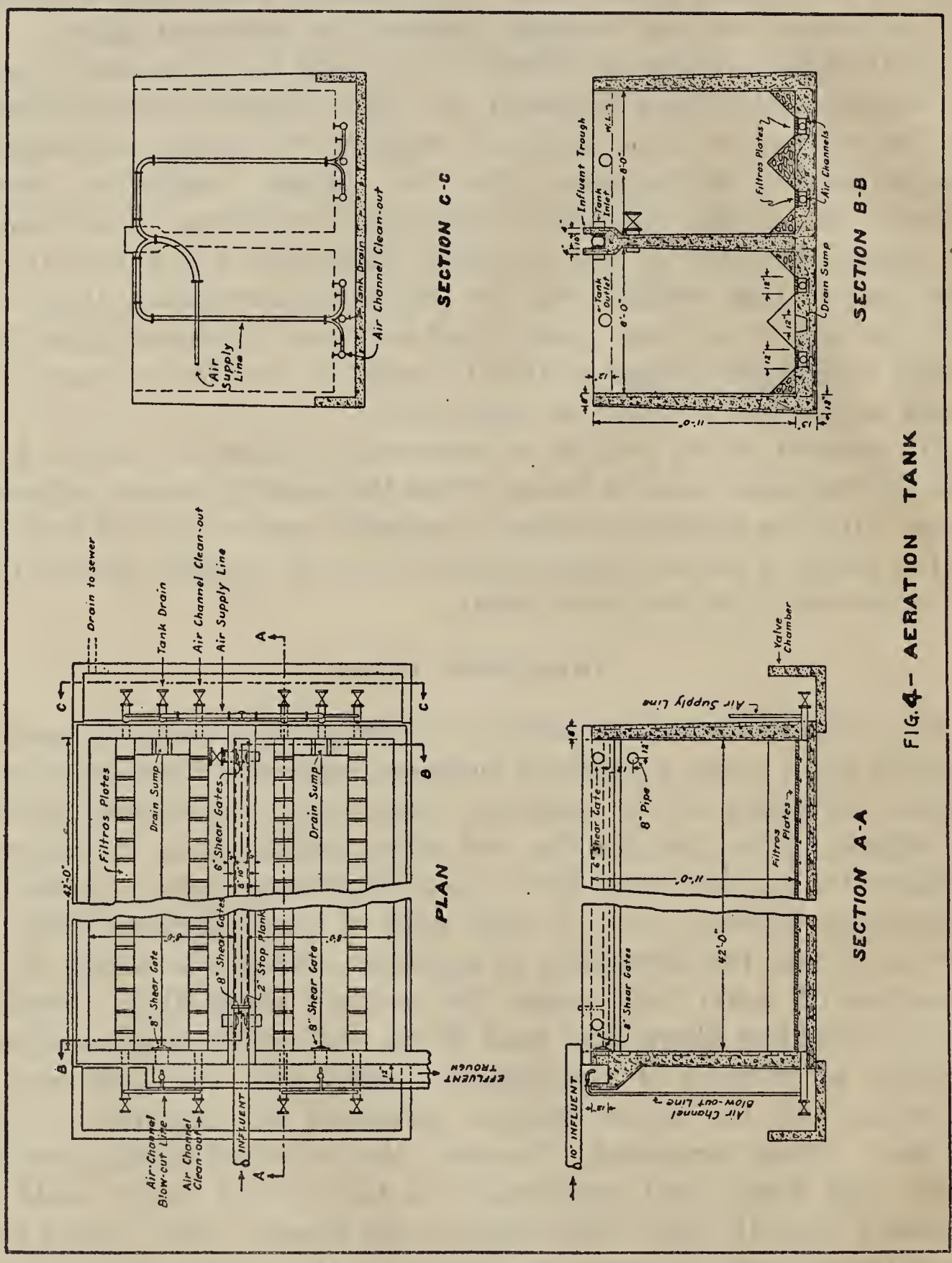

FIG. 4— AERATION TANK

Presettling tank.—Since it was essential that an effluent be obtained of the highest possible quality, and there was some uncertainty as to how the strong domestic sewage would react to the activated sludge treatment, it seemed advisable to install a presettling tank for the purpose of removing as much of the fresh fecal matter and other

coarse material as practicable. The tank was designed for a detention period of 30 minutes at the time of maximum flow. It has hopper bottoms, and the sludge is discharged by gravity into the bypass around the plant. The tank has two sewage outlet pipes, one of which is level with the top of the hoppers and leads to the aeration tanks while the other is near the top of the tank and connects with the lower pipe. This tank, as will be explained later, is also used to store a part of the night flow of sewage.

Diversion chamber.—This is a small chamber located on the line from the presettling tank to the aeration tank for the purpose of bypassing the sewage, when necessary, around the treatment plant.

Aeration tanks.—There are two tanks, each 42 feet by 8 feet by 10 feet deep below the water level, and they were designed to treat approximately 200,000 gallons of sewage daily with an average aeration period of six hours. The design of the tanks is shown in Figure

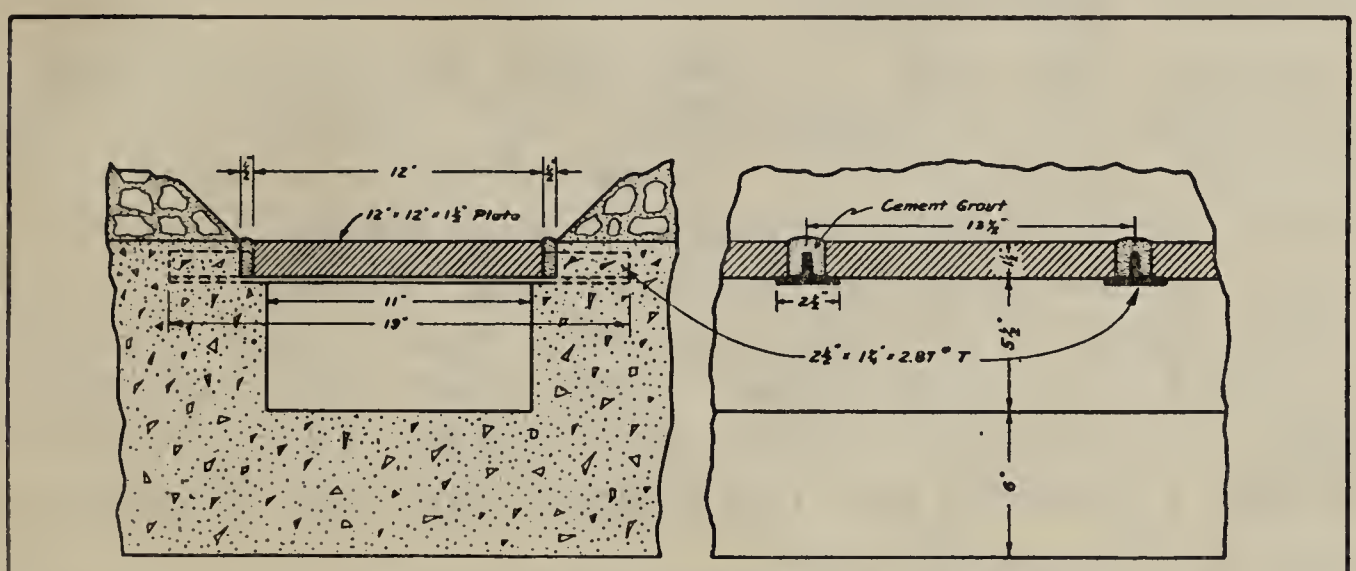

FIG. 5 - DETAILS OF DIFFUSER PLATE INSTALLATION

4. In each tank there are two continuous concrete air channels, each 42 feet long by 11 inches wide by 5½ inches deep. Filtros plates, 12 inches by 12 inches by 1½ inches thick, were grouted into the top of the side walls of the channels, and into T-irons, 2½ inches by 1¼ inches and 2.87 pounds per foot, across the channels, as shown in Figure 5. The air channels at both ends of the tanks have 4-inch pipes that extend through the concrete walls about 2 feet, and on the end of each pipe there is a 4-inch gate valve. These pipes and valves were installed for the purpose of cleaning out the air channels and to permit cleaning the under surfaces of the plates if they should become clogged. The air is applied to the 4-inch pipe at the ends of the tanks nearest the blowers, as shown in Figure 3. At the opposite ends, 2-inch pipes connected to the 4-inch pipes between the valves and the tank walls lead upwards and over the walls into the tank. The 2-inch pipes were installed in order that the sew-

age which accumulates in the air channels when the plant is closed down can be blown up into the tanks instead of through the plates.

No difficulties were encountered in placing the filtros plates over the channels, and there has been no leakage of air around the plates. There was, however, leakage through a short section of one of the ridges of one tank when the plant was first placed in operation, but this leak was easily repaired.

The two tanks are separated by a wall that has at the top a channel which receives the raw sewage from the presettling tank. By means of a stop gate in the channel, the sewage is discharged into the end of one tank and flows out through an opening in the partition wall at the farther end into the other tank and through it to the effluent channel. If it is desired to use only one tank, the sewage is carried in the channel in the top of the partition wall to the farther end of the tanks where it is discharged into either tank and flows back to the effluent channel.

Clarifier.—This tank is 16 feet square and 11½ feet deep and is provided with a scraping device that concentrates the sludge at an outlet pipe in the center. It has a detention period of approximately 2.8 hours with the present flow of sewage, assuming that most of the sewage reaches the plant during 14 hours.

The effluent of the activated sludge tanks enters the clarifier through four openings spaced equally apart along one side and about 1 foot below the surface of the sewage. The effluent flows out over a brass weir plate into a channel that leads to the end of a small secondary settling tank.

Secondary settling tank.—The secondary settling tank is 16 feet by 4 feet by 10 feet deep, and was originally designed as a coagulation basin to be used in connection with the operation of the rapid sand filters. It was found, however, that it was not necessary to use coagulants, and the tank has been used to settle the effluent from the clarifier. An appreciable amount of solids is removed by this tank, and the sludge is discharged through 1-inch openings spaced 1 foot apart in an 8-inch pipe that extends the full length of the bottom of the tank.

Rapid sand filters.—Two filter units were designed, each having an area of 77 square feet. Concrete wash-water troughs were provided, and the underdrainage consists of 12-inch headers with 1¼-inch cast-iron laterals having ¼-inch holes bored on 3-inch centers. The specifications for the coarse sand and gravel were as follows:

8 inches gravel passing 2½-inch mesh screen and retained on 1½-inch mesh.
4 inches gravel passing 1½-inch mesh screen and retained on ¾-inch mesh.
4 inches gravel passing ¾-inch mesh screen and retained on ¼-inch mesh.
4 inches gravel passing ¼-inch mesh screen and retained on $\frac{1}{12}$-inch mesh.

On account of the lack of data regarding the size of sand for rapid sand filters filtering sewage, there was ordered for filter No. 1 a sand having an effective size of 0.35 millimeters and a uniformity coefficient of 1.6, and for filter No. 2 a sand with an effective size of 0.40 millimeters and a uniformity coefficient of 1.6.

Although the sand and gravel delivered were marked in accordance with the specifications, it was found later, when difficulties were experienced in operating the filters, that the sand in filters No. 1 and No. 2 had effective sizes of 0.34 millimeters and 0.23 millimeters and uniformity coefficients of 1.29 and 1.48, respectively.

Loss of head gauges and rate controllers and other equipment were installed so that the filters could be operated in accordance with common practice in water-filtration plants.

Wash-water tank.—Water is delivered to the wash-water tank through a 4-inch pipe line connected to the reclaimed sewage force main, and the flow is regulated by an altitude valve. An 8-inch pipe supplies wash water for the filters.

Clear well.—The clear well is 16 feet square and 5½ feet deep below the overflow. The capacity is 10,500 gallons, but in practice the automatic floats start the pumps in operation when the sewage reaches about 1 foot below the overflow.

Pumping equipment.—The reclaimed sewage is pumped to a steel storage tank by two 4-inch vertical centrifugal pumps which are operated by vertical motors. The tank sets level with the ground and has a capacity of 200,000 gallons. The operation of the pumps is controlled by automatic float switches.

Blowers.—One air compressor with rotor revolving in water, which washes the air, was installed originally and a duplicate unit added a year later. The capacity of each of these units is 200 cubic feet per minute.

Sterilizing equipment.—A semiautomatic chlorine machine is used for applying liquid chlorine to the reclaimed sewage. When either of the pumps start operating, the force of the current in the main moves a vane hanging in the line, and this in turn opens a valve on the chlorine machine that permits chlorine dissolved in water to flow into the clear well at the combined suction of the pumps. When the pumps stop operating the vane falls back to a vertical position and shuts off the chlorine.

In addition to the liquid chlorine machine there is standard equipment for using sodium hypochlorite solution for sterilizing the filter effluents when for any reason liquid chlorine can not be applied. Sodium hypochlorite solution is kept on hand in 5-gallon jugs and everything is ready for use in an emergency.

Wash water recovery tank.—Since every 1,000 gallons of reclaimed sewage that can be used in the place of fresh water is worth $3.09,

a settling tank was installed to collect the wash water from the filters. This tank is 25 feet by 16 feet by 4½ feet deep below the overflow. The capacity is 13,500 gallons, and this is sufficient to store the wash water and permit it to be pumped back to the presettling tank at a low rate over a period of several hours.

OPERATION DATA

Sewage was turned into the treatment plant the latter part of June, 1926, and the effluent was pumped to the storage tank the next day. At first only one aeration tank was used and a fairly satisfactory floc developed within a few days. The floc did not settle out in the clarifier, however, and later there was trouble in keeping the floc down in the tank. As a result the filters clogged quickly. After two months a floc developed which settled in the clarifier, and since then there has been no trouble of a serious nature in operating the plant.

Much of the fine sand has been lost in washing the filters, and new sand has been ordered with an effective size of 0.40 millimeters and a uniformity coefficient of 1.6 for both filters. The coarser sand should give much higher rates.

In Table 1 there are given the more important data pertaining to the operation of the sand filters, aeration tanks, and sterilization of the filter effluent, from May, 1927, to March 31, 1928.

The only sewage lost is that mixed with the sludge drawn off from the presettling tank (600 gallons daily) and the activated sludge that accumulates in excess of the amount required for the operation of the aeration tanks. The total volume of activated sludge wasted per month on the average is about 20,000 gallons.

TABLE 1.—*Data pertaining to operation of sand filters, aeration tanks and sterilization* [1]

Month, 1927-28	Net rate m. g. a. d. for Filter No. — [2]		Per cent wash water Filter No. —		Period between washings (hours) Filter No —		Flow raw sewage, 1,000 gallons	Reclaimed sewage, 1,000 gallons	Amount of air used per gallon, each tank	Aeration period, hours each tank	Chlorine, parts per million	
	1	2	1	2	1	2					Added	Residual at plant
May	20.6	20.6	3.7	3.5	32	32	73	[3] 72			3.6	0.4
June	23.0	23.0	3.4	3.8	50	32	83	81	2.1	5.5	3.6	.4
July	23.9	23.9	2.8	5.0	63	36	85	84	2.0	5.3	3.6	.5
August	24.4	24.4	3.3	3.8	68	53	88	86	2.1	5.1	3.2	.4
September	23.5	23.5	3.5	3.9	64	59	83	82	2.2	5.5	3.7	.5
October	21.0	21.0	3.8	4.2	50	41	75	74	3.0	6.1	4.0	.4
November	22.2	22.2	2.3	2.1	54	59	80	78	2.2	5.6	3.5	.5
December	21.1	21.1	3.8	4.1	47	44	76	75	2.5	6.0	2.7	.5
January	20.5	20.0	2.8	2.5	47	51	73	72	2.4	6.1	2.6	.5
February	21.6	21.6	3.7	3.3	38	39	77	76	2.4	5.8	1.9	.5
March	21.9	21.9	3.3	2.8	49	57	77	76	2.1	5.8	2.3	.5

[1] The figures in the table represent averages of daily records.
[2] Sand practically same size in both filters. This is due to returning to the filters sand lost in washing.
[3] Volume of reclaimed sewage was obtained by meter on force main; that of raw sewage by computation.

From the first of May, 1927, to the end of November, 1927, 98.5 per cent of the sewage was reclaimed; and since December, the laundry waste, amounting to 7,000 gallons daily during the winter and 10,000 gallons in the summer, has been mixed with the sewage and recovered.

As already stated, the air supply lines connect with the four 42-foot air channels under the filtros plates. When the blower is closed down, the sewage filters through the plates and fills the channels. When the air is turned on again, the valves on the 2-inch blow-out lines are opened and the sewage is blown through the pipes into the tank. By this method of operation no sewage is forced back through the plates. The sewage can be blown back through the plates, however, and this has been done frequently. It requires less than one minute to free the channels of sewage after the air pressure is turned into them. The initial air pressure on the channels was 5 pounds per square inch; and after operation of the plant for almost two years, it is only 5½ pounds.

The average amount of air used, approximately 4.6 cubic feet per gallon, for the period covering 11 months, was no doubt more than was required, but it was the normal output of the blower and there would have been no economy in reducing the volume. The aeration period, about 11½ hours, was longer than necessary to produce a satisfactory floc and stable effluent, but the tank capacity was available and it seemed advisable to use it. It is believed that the present tanks and one blower will treat twice the volume of sewage now received at the plant.

An excess of about 0.5 parts per million of free chlorine has been carried in the force main at all times to insure complete sterilization of the reclaimed sewage in the storage tank.

There is an operator in charge of the plant from 7 in the morning until 10 at night. Just before 10 p. m. the sewage in the presettling tank is drawn down to the hoppers and the sludge wasted, and the clear well is pumped out. The blower and aeration tanks operate throughout the night, but generally there is not enough sewage flowing between 10 p. m. and 7 a. m. to fill the presettling tank and clear well. This method of operating the plant has proved entirely satisfactory and saves the labor of one man.

The aeration tanks give most satisfactory results when they contain about 25 per cent of activated sludge. Sludge is returned from the clarifier to the diversion chamber ahead of the aeration tanks by an air lift. Originally a low lift screw type of pump was used for returning the activated sludge, but on account of excessive wear of the bearings an air lift was substituted.

CHEMICAL AND BACTERIOLOGICAL RESULTS

Chemical analyses.—A complete chemical laboratory was installed in April, 1927. The monthly average results of analyses of sewage and effluents for 11 months are given in Table 2.

TABLE 2.—*Monthly average results of analyses of sewage and effluents* [1]

Month 1927–28	Suspended matter, parts per million			Settleable solids, c. c. per liter, 1 hour		Nitrogen in clear well as—			Dissolved oxygen, parts per million, (clear well)	Oxygen demand (5 day), parts per million				Relative stability by methylene blue test (per cent)		Alkalinity as $CaCO_3$ by M. O., parts per million		
	R	C	CW	R	C	NH_3	NO_2	NO_3		R	AS	C	CW	CW	C	R	C	CW
1927																		
May	259	----	4.3	12.0	Tr.	0.56	------	5.6	3.2	----	----	----	1.8	90+	90+	185	----	24
June	244	6.0	3.5	9.1	Tr.	.60	0.33	7.3	3.3	366	0.8	1.5	1.7	90+	90+	169	19	20
July	283	9.0	3.3	13.0	Tr.	.50	.70	5.8	4.1	487	1.3	1.9	1.6	90+	90+	187	27	24
Aug	292	6.0	3.0	10.0	Tr.	.53	.90	4.5	3.8	437	1.6	1.7	1.6	90+	90+	191	39	37
Sept	211	8.0	3.0	9.0	Tr.	.54	.77	3.9	4.0	380	1.1	1.3	1.0	90+	90+	209	38	34
Oct	225	5.0	3.0	11.0	Tr.	.45	.63	4.9	4.4	406	1.3	1.5	1.3	90+	90+	217	22	20
Nov	210	5.0	3.0	7.5	Tr.	.60	1.40	4.4	5.0	390	1.1	1.4	1.4	90+	90+	176	30	28
Dec	214	6.0	3.0	9.7	Tr.	.63	1.00	4.8	5.0	420	1.1	1.3	1.1	90+	90+	163	51	48
1928																		
Jan	201	10.0	5.0	10.0	Tr.	.58	.38	7.0	4.7	403	2.5	2.7	2.3	90+	90+	166	50	51
Feb	193	7.3	3.4	12.0	Tr.	.62	.32	5.8	4.5	388	1.6	1.7	1.6	90+	90+	172	87	86
Mar	207	7.0	4.0	11.0	Tr.	.39	.48	7.1	4.8	351	1.6	1.7	1.6	90+	90+	204	81	81
N	127	119	124	289	210	87	68	87	284	52	51	52	279	307	306	296	268	296

[1] Composite samples.

NOTE.—R=Raw sewage; C=Clarifier; CW=Clear well; AS=Activated sludge tank effluent after settling 30 minutes; N=Number analyses made.

In comparison with the averages of results given in Public Health Bulletin No. 132, "Sewage Treatment in the United States," the settleable solids, suspended matter, and oxygen demand results of analyses of raw sewage at the canyon were, respectively, 278, 23, and 232 per cent stronger than the averages for the 15 cities given in the BULLETIN. The suspended matter in the sand filter effluent at the canyon was consistently below five parts per million, the nitrates were high, and the oxygen demand was below two parts per million. The oxygen demand of the effluents of the aeration tanks and clarifier was likewise uniformly less than two parts per million. The dissolved oxygen was low; and this is explained in part by the fact that at the elevation of the treatment plant (6,866 feet) the solubility of oxygen in water is about 30 per cent less than at sea level. The relative stability of the effluents from the filters and clarifier by the methylene blue test was in every analysis more than 90 per cent.

There is practically no permanent hardness in the sewage at the canyon, and up to the time the laundry waste was treated at the plant, December, 1927, the average of 185 determinations of alka-

linity was 190 parts per million, and for the same number of analyses of the effluent of the clarifier and the sand filters, the averages were, respectively, 29 and 27 parts per million. The effect of the laundry waste on the effluent is discussed later in this paper.

In Public Health Bulletin No. 132, page 13, Table No. 6, there are given the changes in the alkalinity of different sewages on passing through oxidizing devices. The sprinkling filters at Fitchburg reduced the alkalinity from 99 to 8 parts per million; those at Baltimore, 144 to 63; Reading, Pa., 177 to 105; Rochester (Brighton plant), 189 to 131; Lexington, 194 to 152; Atlanta (Intrenchment Creek plant), 82 to 48; Atlanta (Peachtree plant), 69 to 35; and Columbus, 219 to 192. The contact filters at Alliance reduced the alkalinity from 194 to 167, while similar filters at Canton showed an increase of 11 parts per million. The activated sludge plant at Houston (south side) reduced the alkalinity from 304 to 220, and the north side plant, 270 to 198; at San Marcos, Tex., the reduction was from 311 to 239; and at Sherman, Tex., the alkalinity of the effluent was 416, and of the sewage, 415. The reduction of the alkalinity in each plant was almost directly in proportion to the degree of purification effected. At Fitchburg, for example, where 92 per cent of the alkalinity of the sewage was removed by the sprinkling filters, the nitrification was higher and the oxygen demand lower than at any of the other filter plants. The effluent from the activated sludge plant at Sherman, Tex., which was the poorest of all the effluents examined from activated sludge plants, had practically the same alkalinity as the raw sewage. The plant at the Grand Canyon removed 86 per cent of the alkalinity before the laundry waste was treated with the sewage, and 80 per cent afterwards.

In view of the fact that the oxidizing processes of sewage-treatment plants, when producing a high quality of effluent, reduce the alkalinity somewhat in proportion to the extent of oxidation of the organic matter, it is but reasonable to assume that the reduction is associated with the biological activity of the oxidizing devices. This relation, if better understood, might possibly throw more light on the problem of sewage treatment.

The pH value of the raw sewage and activated sludge at the canyon averages 7.0, and the final effluent, 6.3.

Bacteriological results.—Routine bacteriological analyses have been made weekly at the treatment plant since January 1, 1928. A summary of the results is given in Table 3.

TABLE 3.—*Summary of bacteriological analyses*

[Period covered by analyses, Jan. 1 to Mar. 31, 1928]

Total count on agar, 24 hours, 37° C.	
Raw sewage, average 14 analyses	810,000
Aeration tank, average 4 analyses	28,000
Effluent sand filters, average 14 analyses	103
Sterilized effluent in force main, average 14 analyses	2
B. coli	
(1) Raw sewage:	
Number per c. c., average 14 analyses	220,000
Number samples having 1,000 per c. c	1
Number samples having 10,000 per c. c	11
Number samples having 100,000 per c. c	2
(2) Effluent, clarifier:	
Number samples having less than 100 per c. c	1
Number samples having 100 per c. c	10
Number samples having 1,000 per c. c	4
(3) Effluent, sand filters:	
Number samples having less than 1 per c. c	8
Number samples having 1 per c. c	6
(4) Sterilized effluent delivered to storage tank:	
Number 10 c. c. portions tested	70
Number 10 c. c. portions negative	69

The results given in the table show that 99.98 per cent of the bacteria in sewage growing on agar, 24 hours, 37° C., were removed by the treatment plant, and that 99.84 per cent of the *B. coli* in the raw sewage were removed by the aeration tanks and clarifier, and 99.99 per cent by the plant as a whole. Out of the 70 portions of 10-cubic-centimeter samples of the sterilized effluent analyzed, only one was positive for *B. coli*.

Before the bacteriological work was started at the plant, 41 samples of the reclaimed sewage were sent to the Arizona State Board of Health for analysis. Of these, 28 were taken from the force main to the storage tank. The analyses showed that only five of the one hundred and forty 10-cubic-centimeter portions were positive for *B. coli*, and all these portions were from one sample. Thirteen samples were taken from a tap on the reclaimed sewage distribution line in the power house. In one sample all five 10-cubic-centimeter portions were positive for *B. coli*, and in one other sample one portion was positive. All other results were negative.

Since June, 1926, there has been made a total of 55 analyses of samples of the sterilized effluent collected from the force main to the storage tank and from a tap in the reclaimed sewage line in the power house, and five portions of 10 cubic centimeters each were analyzed from each sample. There were, therefore, 275 portions tested. Of these portions, 12, or 4.4 per cent, were positive for *B. coli*. It is believed that these results represent the average quality of the effluent for the entire time the treatment plant has been operated.

RECOVERY OF LAUNDRY WASTES

After the treatment plant had been in operation for a few months and was producing a satisfactory effluent, an investigation was made to determine how the laundry waste could be treated so that it

could be recovered along with the sewage and not interfere with the use of the reclaimed sewage for generating steam. The investigation included chemical precipitation using alum in amounts varying from 10 to 35 grains per gallon. The smallest amount of alum giving satisfactory results was 15 grains per gallon. The averages of the analyses of the compositite waste untreated and treated with 15 grains per gallon were as follows:

	Raw waste	Treated waste
Oxygen demand, five days, parts per million	97	25
Suspended matter, parts per million	221	12
Total solids, parts per million	1,061	864
Alkalinity, parts per million	249	50
Phenol alkalinity, parts per million	7	0
Noncarbonate hardness, parts per million	0	0

The reduction of the alkalinity from 249 to 50 parts per million by using 15 grains of alum per gallon is not in accordance with the reduction found in water treatment plants. The only explanation that can be offered for the reduction of 13 parts per million per grain of alum used is that the untreated laundry waste contained in suspension insoluble precipitates which reacted with the acid of the standard solution, whereas with the treated samples only the clear supernatant fluid which was free of suspended matter, was titrated.

Since the analyses showed that the hardness of the laundry waste was due to carbonates and bicarbonates, and 86 per cent of these constituents was removed from the sewage in the treatment plant, it was not considered necessary to treat the waste. It was mixed with the sewage and treated at the plant beginning December, 1927. The total hardness of the combined sewage and waste after treatment was determined hourly by the soap method for eight days during the hours the waste was passing through the plant. The analyses varied from a minimum of 23 to a maximum of 37 parts per million, with an average of 34. This average is slightly above that for the treated sewage before the waste was added. The monthly average results of soap hardness of the final effluent for January, February, and March were, respectively, 24, 38, and 47 parts per million, while the alkalinity results for the final effluent for the three months were 56, 86, and 81. The higher results for alkalinity were due to the presence in the laundry waste of sodium carbonate, which effects the alkalinity but not the soap hardness.

The suspended matter in the laundry waste was about the same as that in the raw sewage and the oxygen demand about one-fourth.

With the recovery of the laundry waste the amount of reclaimed sewage approaches very closely to 99 per cent of all the water discharged into the sewers.

USES OF RECLAIMED SEWAGE

At the present time the reclaimed sewage is used in stationary boilers for generating steam for heating purposes, and in the locomotives that haul passengers and freight trains on the branch line of the Santa Fe from Williams to the canyon; for cooling water for Diesel engines; for irrigating lawns around the hotel; and for flushing toilets in the public comfort stations in the El Tovar Hotel, Bright Angel Camp, railroad depot, and the Government automobile camp.

The force main from the treatment plant runs direct to the storage tank with only one branch taken off to supply cooling water for the Diesel engines. The entire distribution system from the storage tank is inclosed in vitrified pipes up to the outlets or fixtures where the reclaimed sewage is used. Beyond the vitrified pipe the uncovered distribution lines are painted red. The sewer pipe will prevent cross connections to fresh water lines. The pressure on the fresh water mains is greater than that on the reclaimed sewage lines. No valves, spigots, or any other openings are permitted on reclaimed sewage lines except where absolutely necessary. Accurate maps are kept up to date showing all the fresh water and reclaimed sewage pipe lines and no extensions or alterations of either piping system can be made without the approval of the superintendent of the park. With these limitations and precautions in distributing the reclaimed sewage, and the careful supervision given to the operation of the treatment plant, it is believed that it will be possible to use the reclaimed sewage indefinitely without any danger to the health of visitors to the park or of employees.

There has been no criticism by employees at the canyon who use the reclaimed sewage for generating steam or for any other purposes. The locomotive engineers vigorously opposed the use of "sewage" in passenger engines at first, but after a demonstration by an expert engineer they used the reclaimed sewage and found that it produced less scale than the fresh water obtained at the canyon.

All the reclaimed sewage is now being used for the purposes named above, and no others will be permitted, except possibly the washing of automobiles, under certain restrictions.

The treatment plant is operated under the supervision of a competent sanitary engineer who has two trained assistants.

COST OF OPERATION

In considering the cost of operation, the fact should be kept in mind that the plant was designed and is operated to produce an effluent of the same degree of purity from a bacteriological standpoint as drinking water, and that every 1,000 gallons of reclaimed sewage that can be used in place of fresh water is worth $3.09. The cost

data, therefore, should be considered in relation to water filtration rather than sewage disposal.

The average volume of sewage reclaimed daily during 1927 was 79,000 gallons, and the itemized cost of treatment per 1,000 gallons, was approximately as follows:

Electric current at 5c per kilowatt:	
Operating blower	$0.20
Returning wash water	.003
Operating clarifier	.01
Lighting	.003
Labor for operating plant:	
2 operators and sanitary engineer	.177
Liquid chlorine, oil, grease, repairs to equipment, and extra labor	.009
Interest on investment [1] (treatment plant only)	.086
Depreciation [1] (treatment plant only)	.086
	.574

These costs would be reduced approximately one-half if the plant were operating at the capacity for which it was designed and if electric current were available at the commercial rate charged in cities; and the labor cost would decrease materially for plants treating large volumes of sewage.

CONCLUSIONS

The experience at the canyon has proved that it is possible to produce, continuously, a sewage effluent of the same quality as drinking water, in so far as bacteriological results are concerned, and of better quality than the original water for generating steam.

It is believed that where there is a scarcity of water, particularly in the West and Southwest, it will be economically practicable to reclaim sewage for industrial purposes, and for irrigating any kind of crops without danger of contaminating ground water or the products grown. The same degree of purification, however, will not be required for sewage to be used for irrigation as for industrial purposes, but sterilization will be necessary for reclaimed sewage used in growing vegetables and some other crops. The cost per acre-foot for sterilizing a well-oxidized effluent such as that produced by an activated sludge plant will be approximately $1.20 for small treatment plants using small cylinders of chlorine, and $0.60 for large plants using one-ton containers. The costs for operation of treatment plants will depend on the volume of sewage treated and the prices for labor and materials and for electric current where the activated sludge process is used. Where sewage is reclaimed for industrial purposes or for irrigation, a part of the operating expenses should

[1] Estimates, but believed correct within 2 cents per 1,000 gallons.

logically be charged against the municipalities for disposal of the sewage, and the remainder paid by the parties benefiting by the use of the reclaimed sewage.

No municipality or private corporation should attempt to design a treatment plant to reclaim sewage without the assistance of a competent sanitary engineer, and every plant constructed should be under the supervision of a competent operator.

ACKNOWLEDGMENTS

The treatment plant was designed by the writer, assisted by L. D. Mars, formerly assistant sanitary engineer, United States Public Health Service; M. R. Tillotson, formerly civil engineer of the park and now superintendent; and G. L. Davenport, assistant engineer, Santa Fe Railroad Co. The plant was built jointly by the Government and the Santa Fe Railroad Co. Mr. J. R. Eakin, formerly superintendent of the park, had general supervision over the part built by the Government, with Mr. Tillotson in active charge of construction, and the work done by the Santa Fe was under the general supervision of R. B. Ball, chief engineer coast lines, and G. L. Davenport, assistant engineer.

The plant was operated for one month at the start by Frank R. Shaw, associate sanitary engineer, United States Public Health Service, and he was succeeded by Dario Travaini, who is now in charge and who supplied the chemical and bacteriological analyses given in the tables.

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